

## **F1**

### INTRODUCTION AND OVERVIEW

#### Background: The Green Book

It is now more than ten years since the United States Coast Guard (USCG) issued COMDINST M16562.3, Loran-C User Handbook (the so-called Green Book because of the original color of its cover) in May of 1980. This handbook soon proved very popular and went through several printings. For several years, it stood virtually alone among accessible (semi-technical) discussions of the Loran-C system. Over the years, strong consumer demand caused available stocks of this handbook to be depleted, and finally exhausted.

In the intervening years since this handbook was first written, there have been substantial changes to the loran system from both the hardware and software perspectives. Loran-A (as the original loran system came to be called) was phased out in the United States in favor of the more accurate and longer range Loran-C system. There were many changes and expansions of the Loran-C chains such as the recent expansion of loran coverage to plug the mid-continent gap. New components have been added (e.g., solid-state transmitters, remote operating systems, etc.). Verification surveys to increase system accuracy were completed and new Loran-C charts have been prepared. The identity and location of sources of loran interference have changed substantially. These are just a few of the many changes and other relevant loran developments over the past ten years.

Nor were changes confined to the design and operation of the loran system. There were near-revolutionary advances in the state-of-the-art of loran receiver design (e.g., automated coordinate converters, addition of navigation computers, ability to store and display waypoints, ability to interface with other shipboard electronics, advances in display technology, etc.) that have resulted in the commercial availability of more powerful, easy-to-use, and relatively inexpensive receivers. Taken together, these changes were so substantial as to require a complete rewrite (rather than mere reprinting) of the original USCG Green Book.

#### The New Handbook Edition: More Than Just the Cover Has Changed

This new edition retains many of the useful tables, figures, and charts of the original edition (updated as necessary), but has been considerably expanded in scope to cover the major developments of the past decade. In particular, much more material has been added on how to use loran for navigation to complement the systems information presented in this and the earlier Green Book. Although this handbook is not intended to be an academic treatise on loran navigation, parts of this text, particularly Chapters II and III, are quite technical. Most of the chapters, however, do not presume any extensive technical background on the part of the reader. A comprehensive glossary (Appendix C) and much expanded bibliography (Appendix E) are also included.

To facilitate quick reading and to simplify some of the more technical sections of this handbook, capsule summaries are found throughout the text, set apart in shaded insets. Readers lacking interest in the technical details of these specialized sections can skim these capsule summaries and skip ahead to more interesting topics.



The focus of this handbook is on marine applications of Loran-C. However, aviators may find this handbook useful as wellmentally replace the word mariner with aviator and the vessel icons with aircraft. Lastly, terrestrial users may also find this handbook of interestparticularly the discussions of the system and the technical material in the appendices.

Comments on this handbook are welcome, and should be directed to Commandant (GNRN), United States Coast Guard, Washington, DC 20593 0001.

## Introduction

This introductory chapter provides a brief overview of the loran system and shows how this system compares with other radionavigation systems used in the United States. A simplified discussion of the principle of operation is presented, along with an identification of the components of the loran system. The chapter concludes with a brief history of loran.

Subsequent chapters build upon this basic treatment, detailing the Loran-C system in greater depth (Chapters II and III), Loran-C receivers (Chapter IV), practical aspects of Loran-C navigation (Chapter V), relevant charts (Chapter VI), and installation and related matters (Chapter VII). Numerous appendices provide additional material of a more technical nature.

Readers without any background in loran are advised to read Chapter I, then skip ahead to Chapters IV through VII. Chapters II and III can be deferred for later study and/or skimmed. Readers more familiar with loran and wishing to learn the technical details of this system should read the various chapters in numerical sequence.

## What is Loran?

The name,

loran, is an acronym for long-range navigation.<sup>1</sup> It is a radionavigation system using land-based radio transmitters (operated in the United States by the USCG) and receivers to allow mariners, aviators, and (more recently) those interested in terrestrial navigation to determine their position. Loran-C is the federally provided radionavigation system for the U.S. Coastal Confluence Zone (CCZ). (The CCZ is defined as the area seaward of a harbor entrance to 50 nautical miles offshore or the edge of the Continental Shelf100 fathom curvewhichever is greater. The CCZ does not include the harbor, however. See the glossary in Appendix C for the definitions of specialized terms of art.) Loran-C is also approved as a supplemental air navigation system.

The Federal Aviation Administration (FAA) is presently in the process of certifying Loran-C for non-precision approaches (NPA) conducted under Instrument Flight Rules (IFR). As of this writing only a few such approaches have been established and certified, but the pace of certification is expected to increase substantially in the next few years.

A discussion of the details of the Loran-C system is presented later in this chapter and elsewhere in this handbook. In general terms, however, Loran-C can be characterized as a highly accurate (better than 0.25 nautical mile (NM) absolute accuracy in the defined coverage area), available (99.7% availability), 24-hour-a-day, all-weather<sup>2</sup> radionavigation



system. Loran-C (the present version of this system) coverage extends over the conterminous United States, portions of Alaska, and many other areas of the world.

Loran is also used extensively to establish a precise time reference. Power companies, telephone companies, and many others use Loran-C as a source of timing information for such purposes as controlling and monitoring cesium clocks.

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From the perspective of the mariner, Loran-C is designed to be used in several phases of marine navigation, including ocean navigation and coastal navigation. Loran-C is also a useful supplemental system for harbor and harbor approach navigation. It can also be a valuable supplemental navigation system for inland navigation of recreational vessels. Table I 1 provides brief definitions of these phases of navigation and identifies the navigation techniques and systems commonly in use for each phase.

According to estimates given in the 1990 Federal Radionavigation Plan (FRP), in 1991 there are expected to be more than 572,000 users of the Loran-C system, the second largest user community to employ a single radionavigation system. (According to other estimates, the number of loran users is much larger, perhaps one million or more.) The majority (82%) of Loran-C users are marine users (both domestic and international). Other Loran-C users include U.S. civil aviation users (14%), U.S. civil land users (3.8%), and a small number of Department of Defense (DOD) users. With the exception of DOD applications, which are scheduled to cease as of 31 December 1994, these numbers of Loran-C users are projected to continue to grow in number. Aviation uses of Loran-C, in particular, are expected to increase substantially in the years ahead. Accurate projections of the future number of users depend upon several factors, such as the upcoming (1994) decision by the U.S. Department of Transportation (DOT) whether to continue the Loran-C system, or to begin to phase this system out in favor of other alternatives, such as the Global Positioning System (GPS). Although the outcome of DOT's deliberations cannot be forecast with any certainty, many believe that the Loran-C system will remain in operation well into the next century.

#### Comparison of and Relationship of Loran-C to Other Marine Radionavigation Systems

Before discussing the details of loran, it is useful to understand the role, limitations, and capabilities of the Loran-C system in the context of the overall U.S. radionavigation systems mix. That is, loran should be compared with other competing and complementary radionavigation systems. Table I

2 provides relevant data on the Loran-C system and several other marine radionavigation systems in use throughout the United States and elsewhere. Radionavigation systems included in this comparison include Omega, GPS, marine radiobeacons, and Transit, together accounting for the principal radionavigation systems in use by U.S. mariners. Several key system characteristics of each system, including accuracy, availability, coverage, reliability, fix



rate, fix dimension, system capacity and ambiguity potential are summarized in this table. (Recall that definitions of these and other specialized technical terms can be found in the glossary provided in Appendix C of this handbook.)

### Omega

The Omega system was originally developed and implemented by the Department of the Navy, and now operated by seven nations under the operational control of the USCG. Omega is a very low frequency (VLF 10.2

13.6 kHz) hyperbolic<sup>3</sup> radionavigation system used chiefly for ocean navigation. Table I 3 summarizes the various radio frequency bands, provides a capsule description of the relevant characteristics of each, and identifies past and present radionavigation systems using each band. Position information is obtained by measuring relative phase differences of received Omega signals. There are now eight Omega transmitters. These are located in Norway (at the arctic circle); Monrovia, Liberia; La Reunion Island (in the Indian Ocean); Golfo Nuevo, Argentina; Victoria, Australia; Tsushima, Japan; and in the United States at La Moure, North Dakota, and Oahu, Hawaii. The Omega user community was estimated to number approximately 26,500 in 1991. Under present plans, Omega will remain in operation past the year 2000.

In broad terms (see Table I

2), Loran-C offers superior fix accuracy compared to Omega, but lacks Omegas worldwide coverage. Fix accuracy (more on this in Chapter III) for the Loran-C system within the designated coverage area is no worse than 0.25 NM compared to 2

4 NM for Omega. (Omegas accuracy constraints limit its use to ocean navigation.)

Approximate areas of Loran-C coverage can be found in Appendix B. Although Loran-C coverage exists for many areas of the world, there are also broad expanses of ocean (such as the South Pacific and South Atlantic Oceans) where Loran-C coverage is not available. In contrast, the Omega system offers virtually worldwide coverage. Although not listed among the characteristics given in Table I

2, Loran-C receivers are substantially less expensive than corresponding equipment for Omega and likely to remain so in view of the relative size of the two user communities.

### Global Positioning System (GPS)

GPS is a space-based military and civilian radio positioning system operated by DOD that will provide three-dimensional position, velocity, and tie information to users on or near the surface of the earth. The space component consists of 21 satellites plus three operational spares operating in high altitude (10,900 NM) orbits, and transmitting navigational signals on 1575.42 and 1227.6 MHz. There were an estimated 15,000 GPS users in 1991, a figure projected to grow substantially in the coming years.

GPS is an emerging system that offers improved coverage and accuracy compared to Loran-C, and is the likely successor to the loran (and Omega) system. However, as of this writing, the entire constellation of satellites necessary for continuous worldwide GPS coverage has not been deployed. (According to present plans, the GPS will be fully operation as of 1993. However this schedule may slip.) Additionally, GPS receivers are substantially more expensive than Loran-C receivers, although this price differential will undoubtedly narrow in the future



as the market expands for GPS receivers.

### Marine Radiobeacons

Marine radiobeacons are nondirectional low power radio transmitting stations which operate in the low- and medium-frequency bands (285-325 kHz) to provide ground wave signals to a shipboard receiver equipped with a directional antenna. The receiver, termed a radiodirection finder (RDF) or (typically in aircraft installations) an automatic direction finder (ADF), is used to measure the relative bearing of the transmitter with respect to the user. The line of position (LOP) so determined can be crossed with another derived from a second radiobeacon to determine a fix. (As well an RDF LOP can be advanced or retired and crossed with an earlier or later LOP from the same or another station to determine a running fix.) Currently, there are approximately 200 marine radiobeacons (operated by USCG), located on or near the coasts of the United States.<sup>4</sup> The area of reliable signal reception from these radiobeacons varies with location, but generally includes coastal waters within 200 NM from the shore.

Marine radiobeacons and RDFs provide a redundant or backup system to more sophisticated radionavigation systems. RDF is a popular low-cost, medium-accuracy system for vessels equipped with only minimal radionavigation equipment. Some RDF receivers are powered with self-contained batteries, and can be used in applications where electrical power is at a premium (e.g., sailboats) and/or an independently powered backup navigation system is desired. According to some estimates, the size of the present RDF user community is the largest among U.S. radionavigation systems. It was estimated to number 675,000 users in 1991, but this figure is projected to decrease in the coming years. (Additionally, the present network of RDF stations is being rationalized, and some reductions in their number are being planned.) Under present plans, marine radiobeacons will remain in operation past the year 2000.

Marine radiobeacons are presently under consideration as a component of a differential global positioning system (DGPS). Using this concept, the DGPS signal would be transmitted in concert with a digital GPS correction to increase the accuracy of the GPS. A prototype system at Montauk Point, Long Island, has enabled a position-fixing accuracy of 30 ft (10 meters) to be achieved.

In contrast to Loran-C, marine radiobeacons do not provide sufficient accuracy or coverage to be used as a primary aid to navigation for large vessels in U.S. coastal waters. Although RDF receivers are still being manufactured, there are far fewer makes and models to choose from, compared to the wide variety of commercial Loran-C receivers. The price differential between RDF and Loran-C receivers, once substantially in favor of RDF, has now become almost nonexistent. Moreover, most Loran-C receivers are integrated with special-purpose computers that provide the user with a wealth of additional information of navigational relevance (e.g., ground speed, estimated time enroute, etc.). In contrast, marine radiobeacon receivers offer only the capability to fix the vessels position, and track or home towards or away from the transmitter.

### Transit

As with GPS, the Transitsystem is another DOD operated military and civilian satellite-based system consisting of satellites in approximately 600 NM polar orbits. These satellites transmit



information continuously on 150 and 400 MHz. (Only one frequency is required to determine a position. However, accuracy is increased by using two frequencies.)

Transit offers slightly improved fix accuracy compared to Loran-C, and offers worldwide, but noncontinuous coverage. (Fix rates range from an average of once every 30 minutes at 80 degrees latitude to an average of once every 100 minutes near the equator. Under realistic worst-case conditions (5% of the time) a user must wait as many as six hours between fixes. Dead reckoning is used in the periods between fixes.) Transit receivers are presently much more expensive than corresponding Loran-C receivers and likely to remain so. There were an estimated 95,599 users of the Transit system in 1991. It is anticipated that the Transit system will be phased out in favor of GPS. Under present schedules, operation of the Transit system will be discontinued in 1996.

### Summary

The foregoing discussion, coupled with the material in Tables I

1 and I

2 shows the role and utility of the various radionavigation systems. Loran-C fills an important place in the mix of radionavigation systems and, moreover, has found wide acceptance; Loran-C has at least the second largest number of users of the major radionavigation systems, a point highlighted in Figure I

1. From the perspective of the user, Loran-C offers a proven, easy-to-use, accurate, all-weather radionavigation system applicable (as either a primary or complementary system) to nearly all phases of navigation within designated areas of coverage.

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### Simplified Principle of Loran-C Operation<sup>5</sup>

A more comprehensive technical discussion of the Loran-C system can be found in Chapters II and III. But briefly, the basic Loran-C system consists of a chain of three or more land-based transmitting stations, each separated by several hundred miles. Within the loran chain, one station is designated as a master station (M), and the other transmitters as secondary stations, conventionally designated Victor (V), Whiskey (W), Xray (X), Yankee (Y), and Zulu (Z). For example, the loran chain that serves the northeast United States (NEUS), consists of a master station located in Seneca, New York, with a Whiskey secondary located in Caribou, Maine, an Xray secondary in Nantucket, Massachusetts, a Yankee secondary in Carolina Beach, North Carolina, and a Zulu secondary in Dana, Indiana.

### Figure I

2 illustrates the simplest possible loran chain, called a triad, with a master (denoted M) and two secondary transmitters; Xray (X) and Yankee (Y).

The master station and the secondaries transmit radio pulses at precise time intervals. An on-board Loran-C receiver (depicted by the vessel and aircraft icons in Figure I



2) measures the slight difference in the time that it takes for these pulsed signals to reach the ship or aircraft from both master-secondary pairs. These time differences (TDs) are quite small, and are measured in millionths of a second, microseconds (usec or us). Time differences for each master-secondary pair, denoted (TDX and TDY in Figure I 2) are displayed by the mobile loran receiver.

The difference in the time of arrival of signals from a given master-secondary pair, observed at a point in the coverage area, is a measure of the difference in distance from the vessel to each of the two stations. The locus of points having the same TD from a specific master-secondary pair is a curved line of position (LOP). (Mathematically, these curved LOPs are hyperbolas or, more accurately, spherical or spheroidal hyperbolas on the curved surface of the earth. This is why Loran-C and related systems are termed hyperbolic systems.) The intersection of two or more LOPs from the TDs (shown as TDX-LOP and TDY-LOP in Figure I 2) determine the position of the user (a hyperbolic fix). (This is shown as a circle in Figure I 2, but one course charting convention specifies plotting all electronically determined fixes with a triangular symbol. Using this convention the loran fix would be plotted as a triangle, with the fix time and the word loran written next to the fix parallel to one of the chart axes.)

In practice, the operator simply reads the observed time differences from the Loran-C receiver display, and converts these TD readings to more commonly-used coordinates, such as latitude and longitude, using special charts (termed loran overprinted charts) that display the lattice of possible loran LOPs spaced in convenient units (e.g., every 5 or 10 usec for large-scale charts and at greater intervals for small-scale charts, see Chapter VI for details). Alternatively, most modern loran receivers employ computer algorithms for this coordinate conversion process, and when this feature is selected, an estimate of the users latitude and longitude can be read directly from the loran receiver. (Aviation users deal exclusively in latitude/longitude coordinates.)

Basic marine Loran-C receivers merely displayed measured TDs, so that the navigator was required to fix the vessels position from these TDs and suitable loran charts. Other necessary or useful navigational tasks (e.g., estimating current set and drift, determining course to steer, estimating speeds and times of arrival, etc.) had to be done manually using the fix information supplied by the loran receiver. However, in the past decade, there have been major advances in the state-of-the-art of loran receivers. Most loran receivers now have the ability to determine the vessels (or aircraft's) speed and course over the ground, to define waypoints (points of specified position, such as entrance buoys, turnpoints, wrecks, prime fishing locations, shoals or other hazards to navigation, etc.) and monitor the progress of the vessel or aircraft towards these waypoints, providing such useful information as course corrections, estimated times of arrival, etc. Many loran receivers can interface with other shipboard electronic systems, including radar, autopilots, gyroscopes, fluxgate compasses, speed sensors, and electronic charting systems. These and other useful features of Loran-C receivers are discussed in Chapter IV.

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## Components of the Loran System

Simply put, the components of the Loran system include the land-based facilities, receiver (and associated equipment), and appropriate Loran overprinted charts.

Land-based facilities are highlighted in Figure I

3. These include a master transmitter, at least two secondary transmitters, a control station, a monitor site and time reference. The function of the transmitters are to transmit the Loran signals at precise instants in time. The control station and associated Loran Monitor Sites (LORMONSITES)<sup>6</sup> continually measure the characteristics of the Loran signal as received, detect any anomalies or out-of-tolerance conditions (see Chapter II), and relay this information so that any necessary corrective action can be taken (e.g., to maintain TDs within specified tolerances). Although Loran-C transmitters incorporate extremely accurate cesium clocks as standard equipment, these signals need to be synchronized with standard time references. The U.S. Naval Observatory (USNO) supplies this time reference for the various Loran chains.

The second basic component of the Loran system is the receiver (and associated antenna, antenna coupler, and ground). This receives the Loran signals and converts these into useful navigational information. (Receivers are discussed in Chapter IV.)

The third basic component of the system consists of a set of Loran overprinted nautical charts that enable the mariner to convert the time differences into latitude and longitude. (Loran-C charts are discussed in Chapter VI.) As noted, aviation users work in latitude and longitude terms, so aeronautical charts are not overprinted with Loran TDs.

## A Brief History of Loran

The first

Loranlike hyperbolic radionavigation system was proposed by R. J. Dippy in 1937, and later implemented as the British Gee system in early 1942 (Pierce and Woodward 1971, Pierce 1989, Watson-Watt 1957, Johnson 1978, Webster and Frankland 1961).<sup>7</sup> Gee was a hyperbolic system operated at frequencies from 30 MHz to 80 MHz consisting of master and slave transmitters located approximately 100 miles apart. The choice of the frequency simplified the problem of dealing with the irregular variation of radio signal propagation, but limited the system to nearly a line-of-sight basis. (There is some bending of radio waves, so the distance to the radio horizon is slightly greater than the distance to the visual horizon.) This limitation was of lesser consequence to Gee, because Gee was intended as a system to assist bomber navigation in World War II. Obviously a line-of-sight constraint would severely limit the range of a marine navigation system.

The same principles of hyperbolic radio